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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- An Approach Toward the Implementation of a High Energy Physics and Cosmic Ray Facility in Space

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DATE- July 25, 1969

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AUTHOR(S)- L. Kaufman

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ABSTRACT

The implementation of a high energy physics and cosmic ray program in space will require the study and development of the hardware elements for a space facility that can perform this program. Some of the elements are still in the conceptual stage, others need to be studied for their applicability to the space environment, while others still are already suited to our requirements.

New approaches are suggested for critical elements such as track location hardware and triggering. In the case of track chambers, we suggest that spatial location accuracy can be improved at least by a factor of three by a simple extension of present techniques, and a factor of ten or more by new, and yet untested, solid state techniques. We also propose that triggering using gas Cerenkov counters be replaced by simple fast-logic plastic-scintillator systems. Some other areas of research that promise to be fruitful are presented here. We feel that the costs to carry out this research involved are modest, and the returns worthwhile.

Spacecraft requirements, including the important choice between free-flying and attached modules, also need fur-

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Case 234

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FROM: L. Kaufman

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TECHNICAL MEMORANDUM

I. INTRODUCTION

In a previous work[1] we presented the goals of a space facility intended to study the primary cosmic ray flux and to perform a number of significant experiments in the field of high energy physics.

We discussed the various means by which these goals could be realized, and described a particular conceptual design, one that has as its central component a large superconducting magnet.

In this paper we review the reasons why it is necessary to perform this program in space, the expected role of man and the requirements that lead to the choice of a design based on the use of a magnetic spectrometer. We also present some new approaches in the design of the hardware for the proposed facility, briefly review some concurrent relevant work and present some problems that need further study.

II. REASONS FOR A SPACE FACILITY AND THE ROLE OF MAN

To determine the energy and charge spectra, nuclear composition, and directionality of the primary cosmic ray flux unambiguously, the measurements of interest have to be carried out above the interfering effects of the atmosphere. The reasons for this follow:

1. Since the dynamics of particle interactions are not known at the very high energies of interest, the effects of the atmosphere cannot be accounted for in an unambiguous way. The nuclear and charge spectra are particularly hard to measure since we do know that nuclei breakup shortly after penetrating into the atmosphere.

2. The search for antimatter becomes extremely difficult with even small amounts of atmospheric shielding, since both breakup phenomena and high nucleon annihilation cross-sections comspire to quickly absorb whatever anti-nucleons may be present in the primary flux.

3. The large instruments necessary to measure the interesting parameters of the high energy flux and its interactions in matter, together with the increasing scarcity of particles as their energy increases, creates a need for heavy, long lifetime installations. These factors, coupled with the need to perform the measurements above the atmosphere, makes satellites the natural conveyance for such an installation.

Since long lifetimes are essential, it is assumed that manned maintenance for the facility will be available. This will also provide the versatility necessary for the changing of experimental programs by rearranging the hardware, and the ability to uprate selected pieces of hardware. (We expect that only periodic manned visits to this facility will be necessary.)

III. THE APPROACH

In Reference 1 we proposed that a large superconducting magnet be used as the central element of the facility.* (Fig. 1) Surrounding the magnet there are large ($1 \times 1m^2$ and $2 \times 2m^2$) track location chambers with digitized readout. Other hardware will include charge detection modules, plastic scintillators for triggering purposes, and a large liquid hydrogen target.

The choices for this arrangement were dictated by imposing various requirements on the performance of the facility:

(1) Versatility: to be able to change the experimental program over a wide range of requirements, and to uprate the hardware as this becomes desirable.

(2) Dynamic Range: it is important to measure the energy of individual particles produced in a reaction. These measurements have to be performed over a wide range of energies.

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* As early as 1965, it was recognized that to obtain meaningful results, artificial earth satellites would need to depend on magnetic spectrometers for cosmic ray measurements. At that time V. L. Ginzburg mentions[2] a 30-50 Kgauss, 1-2m diameter superconducting magnet as an ideal (sic) element for this work.

(3) Triggerability: that is, the ability to activate (or trigger) the hardware on events of preselected properties.

(4) The ability to measure the sign of the charge of incoming particles, thus allowing an unambiguous search for antimatter.

(5) Low mass of the hardware in the path of the beam, so that nuclei-nuclei interactions can be studied.

(6) Large Geometry Factor: one of the most troublesome factors in the study of high energy interactions using cosmic rays is the one posed by the dwindling supply of particles as the energy increases. Thus, acceptance is a major consideration when designing the facility.

The question of statistics at high energies is so important that it actually overshadows the one of energy resolution, since the scarcity of particles at the highest energies will require the data to be integrated over a large energy range to obtain meaningful information.

(7) Finally, a point that was touched briefly in Reference 1. Work that we are carrying out concurrently with this leads us to believe that the dynamics of interactions change as the energy increases, the change being such that it would invalidate energy measurements performed with the use of absorbers, such as calorimeters or Total Absorption Nuclear Cascade crystals[3]. Were this to be the case, no unambiguous results on the spectrum of the primary cosmic ray flux, as on cross sections, will be available from measurements with such devices. We expect to address ourselves to this problem in a later communication.

IV. NEW APPROACHES TOWARD MAXIMIZING THE USEFULNESS OF THE MAGNETIC SPECTROMETER

The momentum cut-off for the proposed facility will be linearly dependent on the strength of the magnetic field and the accuracy of location of particle paths provided by the track chambers. (For constant dimensions of the hardware and geometry). The momentum resolution depends on the same parameters.

Thus, it was previously emphasized that the two most fruitful fields of research for this project will be in the area of superconductivity and of particle location hardware.

We proposed that a simple "loop" magnet of the type presently used by the HAPPE project (headed by Dr. Luis Alvarez) be used. In this country, the concept of using a loop originated within the HAPPE project, and is quite attractive in that it eliminates the massive structures necessary to support configurations such as Helmholz Coils. High speed computers can easily handle the momentum analysis through the loop's non-uniform magnetic field.

It is expected that when the money becomes available a 2-m diameter magnet with a central field of about 70 Kgauss will become available. We urge that support be continued in this area of research so that as soon as feasible the operation of a prototype magnet can be tested in space. This step has already been undertaken (successfully) by workers in the Soviet Union.[4]

We present here two new lines of research toward attaining significant improvements in track location by automatic readout devices. The first involves a straight-forward extension of present techniques, while the second involves the development of a new technology. The possibilities and pay-offs involved in each are discussed below:

(1) Improving the spatial resolution of spark chambers without introducing major design changes.*

In spark chambers, the three dominant sources of error in path location are due to

(a) electron diffusion away from the track: The correlation between the measured and actual locations of the track can be roughly estimated by assuming that in the interval between the time when a particle has traversed the spark chamber, and the time at which a sparking voltage is applied, the electrons that initiate the gas discharge diffuse with speeds characteristic of atomic speeds in the gas;

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* This approach has been generated by the author.

(b) "Angle effect": As the angle between the particle's path and the direction of the electric field increases, the spark follows that path with decreasing fidelity;

(c) spark jitter: A certain amount of jitter (or "snaking") can be observed in the sparks, this effect setting a lower limit to the accuracy of track location obtainable in spark chambers.

To deal with these problems we propose that Xenon filled gas spark chambers be tested.

While (a) could be dealt with by increasing the pressure of the 90% Ne-10% He gas mixtures currently used in spark chambers; by lowering the temperature of the gas to, say, liquid air temperatures; or by using liquified gases[5], a simpler approach is to use gases of higher atomic weight, in this case Xe.

A further advantage of Xe over Ne-He is that its higher density will permit thinner gaps, since the minimum gap thickness is fixed by the need that enough electrons be produced by a minimum ionizing particle for the sparking efficiency to be near 100%.

An estimate of the magnitude of the improvement to be obtained by using Xe filled chambers can be arrived at in the following manner: It is found experimentally that for typical times of .5μ sec delay between the passage of a particle and the application of a high voltage pulse, the electrons produced by the particle will drift a distance of the order of .3mm (in the usual 90-10 Ne-He mixture used in spark chambers.) The measured drift yields a velocity of $\sim$600 m/sec, which agrees nicely with the V_{rms}=610 m/sec expected for ideal gas of mass 18.4 at STP conditions.

For an ideal gas of the atomic mass of Xe, V_{rms}=228 m/sec, approximately 2.7 times less than in 90-10 Ne-He. Thus, an improvement in track location of two to three times is expected in Xe.

Furthermore, since the density of Xe is seven times larger, the spark chamber gap could be made one or two millimeters thick without losing efficiency, thus reducing spark jitter and the "angle effect" considerably.

A factor in track location accuracy we have not mentioned is the one of correlation between the spark's location and the coordinate measured. Measurements on magnetostrictive lines performed at Berkeley[6] show that this correlation can be made to be no worse than 20 microns (.02mm). Thus, we are confident that the improvement in spatial resolution will be at least a factor of three, (to ±.1mm), over present spark chambers, but it is of interest to determine just how much the resolution can be improved without resorting to the more drastic methods mentioned above.

(2) Development of solid state spark chambers.

The second approach to the problem of track location over large areas consists in replacing gas spark chambers by larger areas of high resistivity materials, as originally proposed by Dr. V. Perez-Mendez of the Lawrence Radiation Laboratory.[6]

The approach consists in using a material such as Cd S, with resistivity in excess of $10^9\Omega$-cm, which can be deposited over large areas. Originally it was intended to obtain avalanche multiplication of the electrons produced in the material by the ionizing particle, but this posed some problems in technology due to the strict tolerances imposed on the material by requiring such a process to occur uniformly over large areas, but recently workers at Berkeley have attained a large increase in the sensitivity of a magnetostrictive line pick-up,[7] which now is within a factor of 10 of being able to measure the position of particles by detecting the primary charge deposited on relatively thick layers of Cd S ($\sim$1mm) with no further ionization by multiplication. It is also possible to use thin layers ($\sim$10 microns) and to take advantage of the photoconducting gain in Cd S. At present efforts are continuing at Berkeley to improve the sensitivity of the magnetostrictive transducer, and a search for materials with the adequate characteristics is continuing. For instance, Professor Boer at the University of Delaware is convinced of the feasibility of preparing adequate layers of Cd S[8] over large areas.

While solid state track location hardware is still in the conceptual stage, if this line of research is successful we will find ourselves with a relatively simple device that can eventually provide spatial resolutions of the order of a few microns, about ten times better than the best we expect from spark chambers, and comparable to nuclear emulsions. These devices would also be of consequence in the field of γ-ray detection, since their high density would provide efficient conversion. Furthermore, in the case of very high energy γ-rays the upper detection range could be pushed to many GeV, since this limit is determined by whether the opening angle of the conversion electron-positron pair can be measured.

Another advantage of these chambers will consist of the elimination of the windows necessary to maintain gas pressure in spark chambers used in space, and of the gas purifying systems necessary for long life operation.

Given the low level of funding necessary, (of the order of $20,000 each), it appears desirable to support both the Xenon spark chambers and solid state track chamber developments, since under certain conditions (such as those of technology limitations on the size of the solid state devices), hybrid systems may become desirable.

V. HARDWARE COMPLEMENTING THE MAGNETIC SPECTROMETER

The following is a review of current developments in high energy physics instrumentation that is relevant to this work. A new approach towards triggering is presented below.

(1) Charge Measurement Modules: A possible method for charge measurement is described in Reference 9. It consists of measuring dE/dx (proportional to Z^2) in two solid (or liquid) materials and the Cerenkov light output (proportional to Z) in a solid. By knowing the path and momentum of the traversing particle, and comparing these with the three outputs mentioned above, an excellent measure of the charge can be obtained: ± 1 for low Z, ± 3, or better, for the highest Z. Furthermore, determination of the isotopic composition of light nuclei should be possible.

(2) Gamma Detectors: There is a variety of possible approaches to measuring the quantity γ (the ratio of particle energy to rest mass). The most promising are the development of transition[10] and relativistic rise[11] detectors. The use of these devices would allow for easy determination of the mass of the particles of interest.

It is not clear whether gamma-detectors can be built, or whether they will be efficient and convenient enough for space application, but it is certainly valuable to fund feasibility study projects at this time. It is also important that steps be taken to assure that studies of the energy losses of ultrarelativistic particles in materials can be continued at an appropriate pace.

(3) Triggering: During operation of the facility it is of interest to select events above a certain energy. For this purpose the most often mentioned approach involves the use of gas Cerenkov counters. These devices are bulky, have a narrow solid angle acceptance, and gas pressures have to be regulated carefully.

We propose to eliminate the need for gas Cerenkov counters by a system of some 70 scintillators deployed around the outer ring of track chambers (see Fig. 1). To minimize the requirements on the fast logic electronics we propose the following system: Each scintillator triggers a fixed voltage pulser with an output $V_n = kn + b$, where n is the number associated with each plastic scintillator and k and b are constants that can be chosen for convenience. The width of the pulse would be chosen for the desired time resolution, 10 nsec being a conveniently easy to achieve number.

Let us say we have 72 counters, and that n varies from 1 to 37 along each semicircle of counters. Let us now assume that the particles of interest are the ones that bend so that once they go through one counter they are to go through the diametrically opposite counter or either of its two neighbours.

Then, if the outputs of all counters are summed, it is easy to see that the desired events will have an output V such that $(37k + 2b) \leqslant V \leqslant (39b + 2b)$. Thus, a single channel pulse height analyzer set to accept $(36.5k + 2b) \leqslant V \leqslant (39.5k + 2b)$ will provide an acceptable trigger.

To minimize the problem of random pulses due to background, the counters can be organized in groups, each group overlapping its neighbours by one counter. This will minimize interference from accidental triggers.

The same approach can be taken with the outputs of the Cerenkov or dE/dx counters in the charge detection module, thus minimizing random coincidences.

We feel a system such as this will provide for a fast and simple trigger system.

(4) Electronics: The advent of integrated circuitry has produced a third generation of computers that are extremely compact. These computers, tied to computer-controlled fast-logic circuitry[12] and compact digitizing systems for track chamber readout[13], will allow for a reasonably small and versatile electronic system. The on-line partial reduction of data will reduce to acceptable levels the information that will need to be stored and telemetered.

We feel that present advances in the field of integrated circuit computers and logic, and high density data storage systems, allow the needs of the described space facility to be satisfied with today's technology. Future developments will only improve this situation.

VI. AREAS IN NEED OF FURTHER STUDY

(1) Cryogenic System: While we do not expect any major difficulties in the construction of an appropriate liquid helium liquifier, we feel that some of the industrial concerns with expertise in this area should be approached for tentative designs. A small prototype should be tested as soon as feasible.

The development of this liquifier will be of consequence to NASA activities other than the high energy physics programs, since we expect that the need for liquid helium for prolonged times will arise in connection with other programs.

(2) Spacecraft Design: As mentioned in Reference 1, we expect the Cosmic Ray and High Energy Physics Facility to be part of a free flying module, whether a space station exists at the time or not.

The reasons are the following:

(a) The presence of the magnet will create a torque that in a low inclination orbit will reach 660 ft-lb at a radius of 6700 km. This torque may interfere with space station operations that require fine pointing.

(b) The stray magnetic field could create a hazard, since in the free falling environment ferromagnetic materials will tend to drift towards the magnet.

(c) The electromagnetic noise output of the high voltage hardware may interfere with sensitive equipment in the station.

Of course, the facility could be attached to the space station if adequate magnetic and rf shielding were provided, and if the orbit were raised to an altitude such that the magnetic torque (which decreases with the cube of the orbit radius) is decreased to a value such that it can be handled without undue fuel expenditures. A detailed study will be needed to determine the penalties imposed on a space station by a facility such as the one described previously. It should be kept in mind that continuous manned assistance is not considered necessary for this facility.

(3) While we do not expect any problems in this respect, some of the requirements on the module should be studied at this time: the strictest will be placed on dimensional and temperature stability. Relative displacements of the track chambers with respect to each other and the magnet should not vary more than 10 microns over 6 meters. To avoid changes in the dimensions of the chambers themselves the temperature will have to be stabilized to within a few degrees.

VII. CONCLUDING REMARKS

If a timely program in cosmic ray and high energy physics studies is to be a NASA goal we should now encourage the development of the necessary hardware. The cost of this initial step will be minimal, and no large expenditures are expected until actual construction of the facility starts. A vigorous program of manned orbiting operations will be necessary to provide versatility and the useful lifetime that must go with a project of this dimension.

We should not lose sight of the fact that what we propose is a program, and not a set of measurements. As such, it will be a program that must be integrated within the overall effort in this area of science.

The cost of harnessing the "free accelerator in the sky" will be comparable to that of building a storage ring at the National Accelerator Laboratory. Since the techniques of high energy physics are common to the detection of particles whether they are produced by accelerators or cosmic effects, it will be to the project's advantage to make as much use as possible of the expertise and facilities already existent at the major national laboratories. The alternative, to develop in-house facilities, will be a costly one.

Once the decision is made to embark on a program of the type described in Reference 1, then leading members of the high energy physics community, theorists as well as experimentalists, should be involved in the design and construction of this facility.

1015-LK-rghe

L. Kaufman

Attachment
Bibliography
Appendix
Figure 1

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Appendix: A Tentative Time Phased Development Program

1969: Go - No Go Decision

If Go

↓ Fund Basic Hardware Study and Development

Superconducting Magnets
Track Chambers
Cryogenic Systems
Spacecraft Requirements
Gamma Detectors
Other Detectors

↓ Appoint HEP & CR Panel

Start of Study on Goals and Implementation Means

↓

1971: Design Parameters are Narrowed

↓ Mini-system (small superconducting magnet and small track chambers) is tested in orbit (Automated payload or Dry Work Shop)

↓ Bids on hardware construction are requested

↓

1973: Hardware Construction Starts

Accelerator Testing of Components Starts

↓

1975: System Tested on Cosmic Ray Muons and Accelerator

↓

1976: Launch

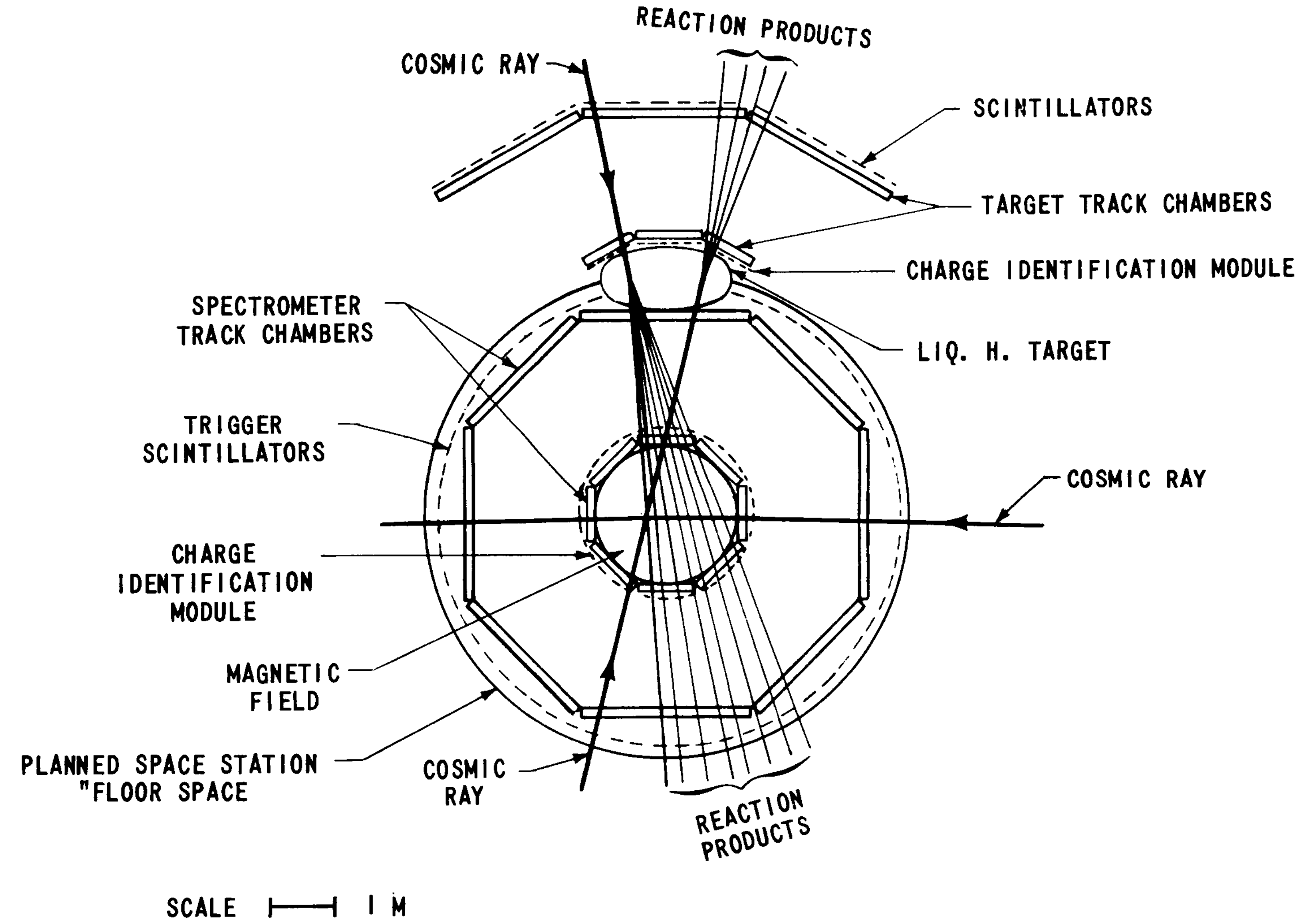

FIGURE 1 - SCHEMATIC LAYOUT OF A HIGH ENERGY PHYSICS AND COSMIC RAY SPACE STATION. THIS CONFIGURATION HAS A GEOMETRY FACTOR $G \sim 8m^2$ sr FOR COSMIC RAYS, AND $G \sim 0.8m^2$ sr FOR HIGH ENERGY PHYSICS EXPERIMENTATION. (FROM REF. 1)